

**XVIII. Report on the best Method of proportioning the Excise upon Spirituous Liquors. By Charles Blagden, M. D. Sec. R. S. and F. A. S.**

Read April 22, 1790.

P A R T I.

*On the Experiments.*

IN consequence of an application from Government to Sir JOSEPH BANKS, Bart. President of the Royal Society, for the best means of ascertaining the just proportion of duty to be paid by any kind of spirituous liquor that should come before the Officers of Excise, I was requested by that Gentleman to assist in planning the proper experiments for this purpose, and to draw up the Report upon them when they should be finished.

Though various indications of the strength of spirituous liquors have been devised, applicable in a gross manner to general use, it is well known that no method admits of real accuracy but that of the specific gravity. The weights of an equal bulk of water and pure spirit differ from one another by at least a sixth part of the weight of the former; whence it is obvious, that, when those two fluids are mixed together, the compound must have some intermediate specific gravity, approaching nearer to that of water or pure spirit, as the former or the latter is the

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more predominant ingredient. Were it not for a certain effect attending the mixture of water and spirits, which has been called their mutual penetration, the specific gravity of these compositions, in a given degree of heat, would be simply in the arithmetical proportion of the quantity of each of the fluids entering into them. But whenever different substances, which have a strong tendency to unite together, are mixed, the resulting compound is found to occupy less space than the substances forming it held in their separate state; wherefore the specific gravity of such compounds is always greater than would be given by a simple calculation from the volume of their ingredients. Though it be a general fact, that such a decrease of bulk takes place on the mixture of substances which have a chemical attraction for each other, yet the quantity of this diminution is different in them all, and, under our present ignorance of the intimate composition of bodies, can be determined by experiment only. To ascertain, therefore, the quantity and law of the condensation resulting from this mutual penetration of water and spirit, was the first object to which the following experiments were directed.

All bodies, in general, expand by heat; but the quantity of this expansion, as well as the law of its progression, are probably not the same in any two substances. In water and spirit they are remarkably different. The whole expansion of pure spirit from  $30^{\circ}$  to  $100^{\circ}$  of FAHRENHEIT's thermometer, is not less than  $\frac{1}{5}$ th of its whole bulk at  $30^{\circ}$ ; whereas that of water, in the same interval, is only  $\frac{1}{4}$ th of its bulk. The laws of their expansion are still more different than the quantities. If the expansion of quicksilver be, as usual, taken for the standard (our thermometers being constructed with that fluid), the expansion of spirit is, indeed, progressively increas-

ing with respect to that standard, but not much so within the above-mentioned interval; whilst water kept from freezing to  $30^{\circ}$ , which may easily be done, will absolutely contract as it is heated for ten or more degrees, that is, to  $40^{\circ}$  or  $42^{\circ}$  of the thermometer, and will then begin to expand as its heat is augmented, at first slowly, and afterwards gradually more rapidly, so as to observe upon the whole a very increasing progression. Now, mixtures of these two substances will, as may be supposed, approach to the less or the greater of those progressions, according as they are compounded of more spirit or more water, whilst their total expansion will be greater, according as more spirit enters into their composition; but the exact quantity of the expansion, as well as law of the progression, in all of them, can be determined only by trials. These were, therefore, the two other principal objects to be ascertained by experiment.

The first step towards a right performance of the experiments was to procure the two substances with which they were to be made as pure as possible. Distilled water is in all cases so nearly alike, that no difficulty occurred with regard to it; but the specific gravity of pure spirit, or alcohol, has been given so very differently by the authors who have treated of it, that a particular set of experiments appeared necessary for determining to what degree of strength rectified spirits could conveniently be brought. The person engaged to make these experiments was Dr. DOLFFUSS, an ingenious Swiss gentleman then in London, who had distinguished himself by several publications on chemical subjects. Dr. DOLFFUSS, having been furnished by Government with spirit for the purpose, rectified it by repeated and slow distillations till its specific gravity became stationary in this manner of operating: he then

added dry caustic alkali to it, let it stand for a few days, poured off the liquor, and distilled it with a small addition of burnt alum, placing the receiver in ice. By this method he obtained a spirit whose specific gravity was ,8188 at 60° of heat. Perceiving, however, that he could not conveniently get the quantity of spirit he wanted lighter than ,82527 at 60°, he fixed upon that strength as a standard, to which he found the above-mentioned lighter spirit could be reduced by adding to it a  $\frac{2}{100}$ th part of water; and with this spirit and distilled water he made a series of experiments for determining the specific gravity of different mixtures of these fluids in different degrees of heat.

The process followed by Dr. DOLLEFUSS is not here given as the best possible for obtaining pure spirit; nor was the result of it, in fact, the lightest alcohol that has been procured. Some spirit has been tried since that time, whose specific gravity was ,813 at 60°. This was furnished by Dr. GEORGE FORDYCE, F. R. S. who succeeded in bringing it to that strength chiefly by adding the alkali very hot. Care must be taken that none of the caustic alkali comes over in the distillation. Some alcohol was also sent, for trial, by Mr. LEWIS, an eminent distiller in Holborn, whose specific gravity, at the same temperature, was ,814.

It was with spirit rectified from malt-spirits that Dr. DOLLEFUSS's series of experiments was made; but he tried several comparative experiments with such as had been rectified from rum and brandy, and found no other difference than might fairly be ascribed to unavoidable errors.

Upon examining the results of Dr. DOLLEFUSS's experiments it was perceived, that though the numbers agreed together tolerably well upon the whole, yet in some places there was

that degree of irregularity in the first differences as made it advisable to repeat several of the experiments; and Dr. DOLLMUSS leaving England about that time, the business of this repetition was intrusted to Mr. GILPIN, Clerk of the Royal Society. This gentleman had already taken a part in the business, by assisting Dr. DOLLMUSS in the former experiments, particularly in the very nice part of weighing the mixtures; and his great skill, accuracy, and patience, in conducting experiments, as well as in computations, had on other occasions been proved to many Members of the Society. One experiment leading on to another, Mr. GILPIN was at length induced to go through the whole series anew; and as the deductions in this Report will be taken chiefly from that last set of experiments, it is proper here to describe minutely the method observed by Mr. GILPIN in his operation. This naturally resolves itself into two parts, the way of making the mixtures, and the way of ascertaining their specific gravity.

1. The mixtures were made by weight, as the only accurate method of fixing the proportions. In fluids of such very unequal expansions by heat as water and alcohol, if measures had been employed, increasing or decreasing in regular proportions to each other, the proportions of the masses would have been sensibly irregular; now the latter was the object in view, namely, to determine the real quantity of spirit in any given mixture, abstracting the consideration of its temperature. Besides, if the proportions had been taken by measure, a different mixture should have been made at every different degree of heat. But the principal consideration was, that with a very nice balance, such as was employed on this occasion, quantities can be determined to much greater exactness by weight, than by any practicable way of measurement. The proportions were, therefore,

fore, always taken by weight. A phial being provided of such a size as that it should be nearly full with the mixture, was made perfectly clean and dry, and being counterpoised, as much of the pure spirit as appeared necessary was poured into it. The weight of this spirit was then ascertained, and the weight of distilled water, required to make a mixture of the intended proportions, was calculated. This quantity of water was then added, with all the necessary care, the last portions being put in by means of a well known instrument, which is composed of a small dish terminating in a tube drawn to a fine point: the top of the dish being covered with the thumb, the liquor in it is prevented from running out through the tube by the pressure of the atmosphere, but instantly begins to issue by drops, or a very small stream, upon raising the thumb. Water being thus introduced into the phial, till it exactly counterpoised the weight, which, having been previously computed, was put into the opposite scale, the phial was shaken, and then well stopped with its glass stopple, over which leather was tied very tight, to prevent evaporation. No mixture was used till it had remained in the phial at least a month, for the full penetration to have taken place; and it was always well shaken before it was poured out to have its specific gravity tried.

2. There are two common methods of taking the specific gravity of fluids; one by finding the weight which a solid body loses by being immersed in them; the other by filling a convenient vessel with them, and ascertaining the increase of weight it acquires. In both cases a standard must have been previously taken, which is usually distilled water; namely, in the first method by finding the weight lost by the solid body in the water, and in the second method, the weight of the

vessel

vessel filled with water. The latter was preferred for the following reasons.

When a ball of glass, which is the properst kind of solid body, is weighed in any spirituous or watery fluid, the adhesion of the fluid occasions some inaccuracy, and renders the balance comparatively sluggish. To what degree this effect proceeds is uncertain; but from some experiments made by Mr. GILPIN, with that view, it appears to be very sensible. Moreover, in this method a large surface must be exposed to the air during the operation of weighing, which, especially in the higher temperatures, would give occasion to such an evaporation as to alter effentially the strength of the mixture. It seemed also, as if the temperature of the fluid under trial could be determined more exactly in the method of filling a vessel, than in the other: for the fluid cannot well be stirred while the ball to be weighed remains immersed in it; and as some time must necessarily be spent in the weighing, the change of heat which takes place during that period will be unequal through the mass, and may occasion a sensible error. It is true, on the other hand, that, in the method of filling a vessel, the temperature could not be ascertained with the utmost precision, because the neck of the vessel employed, containing about ten grains, was filled up to the mark with spirit not exactly of the same temperature, as will be explained presently; but this error, it is suppos'd, would by no means equal the other, and the utmost quantity of it may be estimated very nearly. Finally, it was much easier to bring the fluid to any given temperature when it was in a vessel to be weighed, than when it was to have a solid body weighed in it; because in the former case the quantity was smaller, and the vessel contain-

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ing it more manageable, being readily heated with the hand or warm water, and cooled with cold water: and the very circumstance, that so much of the fluid was not required, proved a material convenience. The particular disadvantage in the method of weighing in a vessel, is the difficulty of filling it with extreme accuracy; but when the vessel is judiciously and neatly marked, the error of filling will, with due care, be exceedingly minute. By several repetitions of the same experiments, Mr. GILPIN seemed to bring it within the  $\frac{1}{1500}$ th part of the whole weight.

The above-mentioned considerations induced me, as well as the gentlemen employed in the experiments, to give the preference to weighing the fluid itself; and that was accordingly the method practised both by Dr. DOLLEFUSS and Mr. GILPIN in their operations.

The vessel chosen as most convenient for the purpose was a hollow glass ball, terminating in a neck of a small bore. That which Dr. DOLLEFUSS used held 5800 grains of distilled water; but, as our balance was so extremely accurate, it was thought expedient, upon Mr. GILPIN's repetition of the experiments, to use one of only 2965 grains capacity, as admitting the heat of any fluid contained in it to be more nicely determined. The ball of this vessel, which may be called the weighing-bottle, measured about 2,8 inches in diameter, and was spherical, except a slight flattening on the part opposite to the neck, which served as a bottom for it to stand upon. Its neck was formed of a portion of a barometer tube, .25 of an inch in bore, and about  $1\frac{1}{2}$  inch long; it was perfectly cylindrical, and on its outside, very near the middle of its length, a fine circle or ring was cut round it with a diamond, as the mark to which it was to be filled

filled with the liquor. This mark was made by fixing the bottle in a lathe, and turning it round with great care, in contact with the diamond. The glass of this bottle was not very thick; it weighed 916 grains, and, with its silver cap, 936.

When the specific gravity of any liquor was to be taken by means of this bottle, the liquor was first brought nearly to the required temperature, and then the bottle was filled with it up to the beginning of the neck only, that there might be room for shaking it. A very fine and sensible thermometer (to be more particularly described hereafter) was then passed through the neck of the bottle into the contained liquor, which shewed whether it was above or below the intended temperature. In the former case the bottle was brought into colder air, or even plunged for a moment in cold water; the thermometer in the mean time being frequently put into the contained liquor, till it was found to sink to the right point. In like manner when the liquor was too cold, the bottle was brought into warmer air, immersed in warm water, or more commonly held between the hands, till upon repeated trials with the thermometer the just temperature was found. It will be understood, that during the course of this heating or cooling, the bottle was very frequently shaken between each immersion of the thermometer; and the top of the neck was kept covered, either with the finger, or a silver cap made on purpose, as constantly as possible. Hot water was used to raise the temperature only in heats of  $80^{\circ}$  and upwards, inferior heats being obtained by applying the hands to the bottle; when the hot water was employed, the ball of the bottle was plunged into it and again quickly lifted out, with the necessary shaking interposed, as

often as was necessary for communicating the required heat to the liquor; but care was taken to wipe the bottle dry after each immersion, before it was shaken, lest any adhering moisture might by accident get into it. The liquor having by these means been brought to the desired temperature, the next operation was to fill up the bottle exactly to the mark upon the neck, which was done with some of the same liquor, by means of a glass funnel with a very small bore. Mr. GILPIN endeavoured to get that portion of the liquor which was employed for this purpose, pretty nearly to the temperature of the liquor contained in the bottle; but as the whole quantity to be added never exceeded ten grains, a difference of ten degrees in the heat of that small quantity, which is more than it ever amounted to, would have occasioned an error of only  $\frac{1}{30}$  of a degree in the temperature of the mass. Enough of the liquor was put in, to fill the neck rather above the mark, and the superfluous quantity was then absorbed to great nicety, by bringing into contact with it the fine point of a small roll of blotting paper. As the surface of the liquor in the neck would be always concave, the bottom or centre of this concavity was the part made to coincide with the mark round the glass: and in viewing it care was taken, that the near and opposite sides of the mark should appear exactly in the same line, by which means all parallax was avoided. A silver cap, which fitted tight, was then put upon the neck, to prevent evaporation; and the whole apparatus was in that state laid in the scale of the balance, to be weighed with all the exactness possible.

The spirit employed by Mr. GILPIN was furnished to him by Dr. DOLFFUSS, under whose inspection it had been rectified from rum supplied by Government. Its specific gravity, at 60

degrees of heat, was ,82514. It was first weighed pure, in the above-mentioned bottle, at every five degrees of heat, from 30 to 100 inclusively. Then mixtures were formed of it and distilled water, in every proportion from  $\frac{1}{20}$ th of the water to equal parts of water and spirit; the quantity of water added being successively augmented, in the proportion of five grains to one hundred of the spirit; and these mixtures were also weighed in the bottle, like the pure spirit, at every 5 degrees of heat. The numbers hence resulting are delivered in the following table; where the first column shews the degrees of heat; the second gives the weight of the pure spirit contained in the bottle at those different degrees; the third gives the weight of a mixture in the proportions of 100 parts by weight of that spirit to 5 of water, and so on successively till the water and the spirit are in equal parts. The bottle itself, with its cap, having been previously counterpoised, these numbers are the weights of the liquor contained in it, in grains and hundredths of a grain. They are the mean of three several experiments at least, as Mr. GILPIN always filled and weighed the bottle over again that number of times, if not oftener. The heat was taken at the even degree, as shewn by the thermometer, without any allowance in the first instance, because the coincidence of the mercury with a division can be perceived more accurately than any fraction can be estimated; and the errors of the thermometers, if any, it was supposed would be less upon the grand divisions of 5 degrees, than in any others. It must be observed, that Mr. GILPIN used the same mixture throughout all the different temperatures, heating it up from 30° to 100°; hence some small error

in its strength may have been occasioned, in the higher degrees, by more spirit evaporating than water; but this, it is believed, must have been trifling, and greater inconvenience would probably have resulted from interposing a fresh mixture.

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T A B L E I.

Weights at the different degrees of temperature.

| Heat. | The pure spirit.                            | 100 grains of spirit to 5 grains of water.  | 100 grains of spirit to 10 grains of water. | 100 grains of spirit to 15 grains of water. | 100 grains of spirit to 20 grains of water. | 100 grains of spirit to 25 grains of water. | 100 grains of spirit to 30 grains of water. | 100 grains of spirit to 35 grains of water. | 100 grains of spirit to 40 grains of water. | 100 grains of spirit to 45 grains of water.  | 100 grains of spirit to 50 grains of water. |
|-------|---|---|---|---|---|---|---|---|---|--|---|
| °     | Grains.                                      | Grains.                                     |
| 30    | 2487,32                                     | 2519,98                                     | 2548,59                                     | 2573,86                                     | 2596,65                                     | 2617,24                                     | 2636,16                                     | 2653,54                                     | 2669,64                                     | 2684,63                                      | 2698,41                                     |
| 35    | 2480,79                                     | 2513,48                                     | 2541,96                                     | 2567,34                                     | 2590,15                                     | 2610,80                                     | 2629,77                                     | 2647,30                                     | 2663,48                                     | 2678,43                                      | 2692,32                                     |
| 40    | 2474,18                                     | 2506,98                                     | 2535,52                                     | 2560,83                                     | 2583,70                                     | 2604,50                                     | 2623,42                                     | 2641,02                                     | 2657,35                                     | 2672,37                                      | 2686,37                                     |
| 45    | 2467,52                                     | 2500,33                                     | 2528,90                                     | 2554,24                                     | 2577,16                                     | 2597,99                                     | 2617,04                                     | 2634,68                                     | 2650,96                                     | 2666,13                                      | 2680,25                                     |
| 50    | 2460,77                                     | 2493,48                                     | 2522,10                                     | 2547,61                                     | 2570,64                                     | 2591,50                                     | 2610,59                                     | 2628,26                                     | 2644,68                                     | 2659,95                                      | 2674,04                                     |
| 55    | 2453,84                                     | 2486,51                                     | 2515,30                                     | 2540,88                                     | 2563,94                                     | 2584,79                                     | 2604,07                                     | 2621,77                                     | 2638,25                                     | 2653,55                                      | 2667,72                                     |
| 60    | 2446,86                                     | 2479,75                                     | 2508,60                                     | 2534,19                                     | 2557,23                                     | 2578,22                                     | 2597,50                                     | 2615,26                                     | 2631,82                                     | 2647,20                                      | 2661,45                                     |
| 65    | 2440,04                                     | 2472,97                                     | 2501,87                                     | 2527,51                                     | 2550,56                                     | 2571,48                                     | 2590,86                                     | 2608,72                                     | 2625,41                                     | 2640,80                                      | 2655,09                                     |
| 70    | 2433,37                                     | 2466,28                                     | 2495,00                                     | 2520,65                                     | 2543,84                                     | 2564,89                                     | 2584,23                                     | 2602,14                                     | 2618,89                                     | 2634,30                                      | 2648,65                                     |
| 75    | 2426,47                                     | 2459,18                                     | 2488,03                                     | 2513,63                                     | 2536,91                                     | 2558,14                                     | 2577,47                                     | 2595,43                                     | 2612,20                                     | 2627,78                                      | 2642,17                                     |
| 80    | 2419,18                                     | 2451,95                                     | 2480,83                                     | 2506,61                                     | 2529,85                                     | 2551,10                                     | 2570,52                                     | 2588,61                                     | 2605,32                                     | 2621,03                                      | 2635,47                                     |
| 85    | 2412,02                                     | 2444,80                                     | 2473,68                                     | 2499,59                                     | 2523,08                                     | 2544,41                                     | 2563,80                                     | 2581,91                                     | 2598,76                                     | 2614,48                                      | 2628,87                                     |
| 90    | 2404,92                                     | 2437,72                                     | 2466,64                                     | 2492,62                                     | 2516,20                                     | 2537,57                                     | 2556,95                                     | 2575,20                                     | 2592,17                                     | 2607,86                                      | 2622,30                                     |
| 95    | 2397,75                                     | 2430,56                                     | 2459,51                                     | 2485,51                                     | 2509,15                                     | 2530,51                                     | 2549,95                                     | 2568,18                                     | 2585,12                                     | 2601,12                                      | 2615,70                                     |
| 100   | 2390,64                                     | 2423,53                                     | 2452,63                                     | 2478,59                                     | 2502,15                                     | 2523,59                                     | 2543,08                                     | 2561,28                                     | 2578,37                                     | 2594,45                                      | 2609,11                                     |
| Heat. | 100 grains of spirit to 55 grains of water. | 100 grains of spirit to 60 grains of water. | 100 grains of spirit to 65 grains of water. | 100 grains of spirit to 70 grains of water. | 100 grains of spirit to 75 grains of water. | 100 grains of spirit to 80 grains of water. | 100 grains of spirit to 85 grains of water. | 100 grains of spirit to 90 grains of water. | 100 grains of spirit to 95 grains of water. | 100 grains of spirit to 100 grains of water. |   |
| °     | Grains.                                      | Grains.                                     |
| 30    | 2711,19                                     | 2723,00                                     | 2733,84                                     | 2744,19                                     | 2753,67                                     | 2762,61                                     | 2771,26                                     | 2779,21                                     | 2786,47                                     | 2793,26                                      |   |
| 35    | 2705,08                                     | 2716,96                                     | 2727,78                                     | 2738,24                                     | 2747,90                                     | 2756,97                                     | 2765,47                                     | 2773,53                                     | 2780,75                                     | 2787,59                                      |   |
| 40    | 2699,09                                     | 2711,02                                     | 2721,90                                     | 2732,45                                     | 2742,18                                     | 2751,35                                     | 2759,85                                     | 2767,78                                     | 2775,15                                     | 2782,06                                      |   |
| 45    | 2692,97                                     | 2704,82                                     | 2715,98                                     | 2726,38                                     | 2736,21                                     | 2745,47                                     | 2754,13                                     | 2762,03                                     | 2769,55                                     | 2776,40                                      |   |
| 50    | 2686,81                                     | 2698,63                                     | 2709,92                                     | 2720,37                                     | 2730,27                                     | 2739,52                                     | 2748,22                                     | 2756,25                                     | 2763,67                                     | 2770,62                                      |   |
| 55    | 2680,57                                     | 2692,44                                     | 2703,67                                     | 2714,27                                     | 2724,20                                     | 2733,47                                     | 2742,25                                     | 2750,32                                     | 2757,82                                     | 2764,72                                      |   |
| 60    | 2674,31                                     | 2686,16                                     | 2697,44                                     | 2708,18                                     | 2718,26                                     | 2727,56                                     | 2736,26                                     | 2744,32                                     | 2751,87                                     | 2758,82                                      |   |
| 65    | 2667,97                                     | 2680,00                                     | 2691,22                                     | 2701,99                                     | 2712,06                                     | 2721,47                                     | 2730,27                                     | 2738,35                                     | 2745,93                                     | 2752,82                                      |   |
| 70    | 2661,67                                     | 2673,68                                     | 2685,02                                     | 2695,66                                     | 2705,87                                     | 2715,40                                     | 2724,22                                     | 2732,42                                     | 2740,00                                     | 2746,88                                      |   |
| 75    | 2655,19                                     | 2667,32                                     | 2678,60                                     | 2689,34                                     | 2699,57                                     | 2709,08                                     | 2717,95                                     | 2726,25                                     | 2733,92                                     | 2740,83                                      |   |
| 80    | 2648,47                                     | 2660,69                                     | 2672,02                                     | 2682,77                                     | 2693,03                                     | 2702,57                                     | 2711,50                                     | 2719,78                                     | 2727,49                                     | 2734,49                                      |   |
| 85    | 2641,85                                     | 2654,19                                     | 2665,54                                     | 2676,40                                     | 2686,77                                     | 2696,33                                     | 2705,37                                     | 2713,69                                     | 2721,47                                     | 2728,60                                      |   |
| 90    | 2635,38                                     | 2647,61                                     | 2659,07                                     | 2670,09                                     | 2680,60                                     | 2690,22                                     | 2699,10                                     | 2707,44                                     | 2715,22                                     | 2722,32                                      |   |
| 95    | 2628,83                                     | 2641,10                                     | 2652,56                                     | 2663,64                                     | 2674,20                                     | 2683,79                                     | 2692,81                                     | 2701,18                                     | 2708,91                                     | 2716,04                                      |   |
| 100   | 2622,22                                     | 2634,38                                     | 2645,95                                     | 2657,14                                     | 2667,61                                     | 2677,25                                     | 2686,36                                     | 2694,76                                     | 2702,50                                     | 2709,75                                      |   |

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In order to deduce the specific gravities from the numbers in the preceding table, it was necessary to weigh distilled water in the same vessel. This Mr. GILPIN did, in the same manner as before, at the different degrees of heat; and the result of his experiments is delivered in the following table, where the first column shews the heat, and the second gives the weight of the water, at that temperature, contained in the bottle.

## T A B L E II.

## Weights and specific Gravities of distilled Water.

| Heat. | Weight of<br>the<br>water. | Specific gra-<br>vity of the<br>water. |
|-------|----------------------------|--|
|       | Grains.                    |  |
| 30°   |                            |  |
| 35    | 2967,03                    | 1,00087                                |
| 40    | 2967,34                    | 1,00091                                |
| 45    | 2967,29                    | 1,00084                                |
| 50    | 2966,97                    | 1,00066                                |
| 55    | 2966,39                    | 1,00040                                |
| 60    | 2965,39                    | 1,00000                                |
| 65    | 2964,17                    | ,99952                                 |
| 70    | 2962,72                    | ,99896                                 |
| 75    | 2961,03                    | ,99832                                 |
| 80    | 2959,13                    | ,99762                                 |
| 85    | 2957,03                    | ,99685                                 |
| 90    | 2954,80                    | ,99602                                 |
| 95    | 2952,20                    | ,99507                                 |
| 100   | 2949,36                    | ,99404                                 |

There

There would be two methods of computing the specific gravity, at the different temperatures, from these numbers; one, by taking the weight of the water, at the particular temperature in question, for the standard; and the other by fixing on one certain temperature of the water, for instance  $60^{\circ}$ , to be the standard, with its bulk at which that of the spirit at all different degrees shall be compared. I have preferred the latter method, though not the most usual, because it shews, more readily and simply, the progression observed in the changes of specific gravity, according to the heat and strength of the mixture. This method, however, rendered it necessary to make an allowance for the contraction and expansion of the bottle used for weighing the liquors, according to the deviation of their temperature from  $60^{\circ}$ , either below or above. To obtain this correction, the expansion of hollow glass was taken from General Roy's experiments in the LXVth volume of the Philosophical Transactions, as ,0000517 of an inch upon a foot for every degree of heat, whence its effect, in enlarging the capacity of a sphere, was computed, and the resulting correction added to the weight of the liquors in heats below  $60^{\circ}$ , and subtracted from it in heats above. On the same account a third column is given, in the preceding table, to shew the specific gravity of water at the different temperatures, its weight at  $60^{\circ}$  being taken as the standard.

Another correction also became necessary, on account of the part of the stem of the thermometer which was not immersed in the liquor. This instrument, made by RAMSDEN, had its ball ,22 of an inch in diameter, and its stem 13 inches in length. From the ball to the commencement of the scale 3,6 inches of the stem were bare, and then the scale began, which reached

reached from 15 to 110 degrees. The part of it particularly made use of in these experiments, namely, from  $30^{\circ}$  to  $100^{\circ}$ , measured 6,82 inches. The scale was made of ivory, and carried divisions to every fifth of a degree, the quarters of which could be readily estimated; so that the instrument could be read off to twentieths of degrees. When the thermometer was immersed in the weighing-bottle, the liquor reached up nearly to what would have been  $0^{\circ}$  upon its stem; hence, as the heat of the room in which the experiments were made remained about  $60^{\circ}$ , the correction for the different heat of the quicksilver in the stem from that in the ball of the thermometer was calculated according to Mr. CAVENDISH's table, given in the LXVIIth volume of the Philosophical Transactions. Thus the real heat of the fluid in the weighing-bottle being found, an allowance was made to reduce it to the exact degree indicated on the scale of the thermometer.

The precise specific gravity of the pure spirit employed was ,82514; but to avoid an inconvenient fraction it is taken, in constructing the table of specific gravities, as ,825 only, a proportionable deduction being made from all the other numbers. Thus the following table gives the true specific gravity, at the different degrees of heat, of a pure rectified spirit, whose specific gravity at  $60^{\circ}$  is ,825, together with the specific gravities of different mixtures of it with water, at those different temperatures, as far as equal parts by weight.

## T A B L E III.

Real specific gravities at the different temperatures.

| Heat. | The pure spirit. | 100 grains of spirit to 5 grains of water.  | 100 grains of spirit to 10 grains of water. | 100 grains of spirit to 15 grains of water. | 100 grains of spirit to 20 grains of water. | 100 grains of spirit to 25 grains of water. | 100 grains of spirit to 30 grains of water. | 100 grains of spirit to 35 grains of water. | 100 grains of spirit to 40 grains of water. | 100 grains of spirit to 45 grains of water. | 100 grains of spirit to 50 grains of water.  |
|-------|------------------|---|---|---|---|---|---|---|---|---|--|
| 30°   | ,83899           | ,85001                                      | ,85067                                      | ,86819                                      | ,87589                                      | ,88284                                      | ,88922                                      | ,89509                                      | ,90053                                      | ,90558                                      | ,91023                                       |
| 35    | ,83673           | ,84776                                      | ,85737                                      | ,86592                                      | ,87363                                      | ,88061                                      | ,88700                                      | ,89292                                      | ,89839                                      | ,90342                                      | ,90811                                       |
| 40    | ,83445           | ,84551                                      | ,85515                                      | ,86367                                      | ,87140                                      | ,87843                                      | ,88481                                      | ,89074                                      | ,89626                                      | ,90133                                      | ,90605                                       |
| 45    | ,83215           | ,84321                                      | ,85286                                      | ,86140                                      | ,86913                                      | ,87617                                      | ,88260                                      | ,88855                                      | ,89405                                      | ,89916                                      | ,90393                                       |
| 50    | ,82981           | ,84084                                      | ,85051                                      | ,85910                                      | ,86688                                      | ,87392                                      | ,88036                                      | ,88632                                      | ,89187                                      | ,89702                                      | ,90177                                       |
| 55    | ,82741           | ,83843                                      | ,84815                                      | ,85677                                      | ,86455                                      | ,87159                                      | ,87809                                      | ,88406                                      | ,88963                                      | ,89479                                      | ,89957                                       |
| 60    | ,82500           | ,83609                                      | ,84583                                      | ,85445                                      | ,86223                                      | ,86931                                      | ,87582                                      | ,88181                                      | ,88740                                      | ,89259                                      | ,89741                                       |
| 65    | ,82262           | ,83374                                      | ,84350                                      | ,85213                                      | ,85991                                      | ,86698                                      | ,87352                                      | ,87954                                      | ,88518                                      | ,89037                                      | ,89518                                       |
| 70    | ,82032           | ,83142                                      | ,84111                                      | ,84975                                      | ,85758                                      | ,86469                                      | ,87121                                      | ,87725                                      | ,88291                                      | ,88810                                      | ,89294                                       |
| 75    | ,81792           | ,82896                                      | ,83869                                      | ,84731                                      | ,85517                                      | ,86234                                      | ,86886                                      | ,87491                                      | ,88058                                      | ,88585                                      | ,89068                                       |
| 80    | ,81543           | ,82649                                      | ,83623                                      | ,84491                                      | ,85276                                      | ,85993                                      | ,86648                                      | ,87258                                      | ,87822                                      | ,88352                                      | ,88839                                       |
| 85    | ,81291           | ,82396                                      | ,83371                                      | ,84243                                      | ,85036                                      | ,85757                                      | ,86411                                      | ,87021                                      | ,87590                                      | ,88120                                      | ,88605                                       |
| 90    | ,81044           | ,82150                                      | ,83126                                      | ,84001                                      | ,84797                                      | ,85518                                      | ,86172                                      | ,86787                                      | ,87360                                      | ,87889                                      | ,88376                                       |
| 95    | ,80794           | ,81900                                      | ,82877                                      | ,83753                                      | ,84550                                      | ,85272                                      | ,85928                                      | ,86542                                      | ,87114                                      | ,87654                                      | ,88146                                       |
| 100   | ,80548           | ,81657                                      | ,82639                                      | ,83513                                      | ,84308                                      | ,85031                                      | ,85688                                      | ,86302                                      | ,86879                                      | ,87421                                      | ,87915                                       |
| Heat. |                  | 100 grains of spirit to 55 grains of water. | 100 grains of spirit to 60 grains of water. | 100 grains of spirit to 65 grains of water. | 100 grains of spirit to 70 grains of water. | 100 grains of spirit to 75 grains of water. | 100 grains of spirit to 80 grains of water. | 100 grains of spirit to 85 grains of water. | 100 grains of spirit to 90 grains of water. | 100 grains of spirit to 95 grains of water. | 100 grains of spirit to 100 grains of water. |
| 30°   | ,91454           | ,91853                                      | ,92219                                      | ,92568                                      | ,92888                                      | ,93191                                      | ,93483                                      | ,93751                                      | ,93996                                      | ,94225                                      |  |
| 35    | ,91242           | ,91644                                      | ,92009                                      | ,92362                                      | ,92687                                      | ,92995                                      | ,93281                                      | ,93553                                      | ,93796                                      | ,94027                                      |  |
| 40    | ,91034           | ,91438                                      | ,91805                                      | ,92161                                      | ,92489                                      | ,92799                                      | ,93086                                      | ,93353                                      | ,93602                                      | ,93835                                      |  |
| 45    | ,90822           | ,91222                                      | ,91599                                      | ,91950                                      | ,92281                                      | ,92595                                      | ,92887                                      | ,95153                                      | ,93407                                      | ,93638                                      |  |
| 50    | ,90608           | ,91007                                      | ,91388                                      | ,91740                                      | ,92075                                      | ,92388                                      | ,92681                                      | ,92952                                      | ,93202                                      | ,93436                                      |  |
| 55    | ,90390           | ,90791                                      | ,91170                                      | ,91528                                      | ,91863                                      | ,92176                                      | ,92472                                      | ,92744                                      | ,92997                                      | ,93230                                      |  |
| 60    | ,90173           | ,90570                                      | ,90954                                      | ,91316                                      | ,91656                                      | ,91971                                      | ,92264                                      | ,92536                                      | ,92791                                      | ,93025                                      |  |
| 65    | ,89952           | ,90359                                      | ,90738                                      | ,91100                                      | ,91440                                      | ,91769                                      | ,92055                                      | ,92328                                      | ,92584                                      | ,92816                                      |  |
| 70    | ,89733           | ,90136                                      | ,90522                                      | ,90880                                      | ,91225                                      | ,91547                                      | ,91845                                      | ,92121                                      | ,92377                                      | ,92608                                      |  |
| 75    | ,89507           | ,89916                                      | ,90298                                      | ,90660                                      | ,91005                                      | ,91326                                      | ,91625                                      | ,91909                                      | ,92164                                      | ,92397                                      |  |
| 80    | ,89277           | ,89690                                      | ,90072                                      | ,90435                                      | ,90780                                      | ,91103                                      | ,91404                                      | ,91683                                      | ,91943                                      | ,92179                                      |  |
| 85    | ,89043           | ,89460                                      | ,89843                                      | ,90209                                      | ,90558                                      | ,90882                                      | ,91186                                      | ,91465                                      | ,91729                                      | ,91969                                      |  |
| 90    | ,88817           | ,89230                                      | ,89617                                      | ,89988                                      | ,90342                                      | ,90668                                      | ,90967                                      | ,91248                                      | ,91511                                      | ,91751                                      |  |
| 95    | ,88588           | ,89003                                      | ,89390                                      | ,89763                                      | ,90119                                      | ,90443                                      | ,90747                                      | ,91029                                      | ,91290                                      | ,91531                                      |  |
| 100   | ,88357           | ,88769                                      | ,89158                                      | ,89536                                      | ,89889                                      | ,90215                                      | ,90522                                      | ,90805                                      | ,91066                                      | ,91310                                      |  |

From

From this table, when the specific gravity of any spirituous liquor is ascertained, it will be easy to find the quantity of rectified spirit, of the above-mentioned standard, contained in any given quantity of it, either by weight or measure. As common arithmetic is competent to furnish the rules for this purpose, it would be superfluous to give them here. All the objects of inquiry relative to this business should, I think, be reduced to Tables; the first of which might exhibit the specific gravities of different mixtures, from one to 100 parts of water, increasing by one, at every degree of heat from 40 to 80, being the utmost limits of temperature that can be wanted in common practice. This table need only be calculated to three places of figures, which will always give the quantity of spirit true within a fiftieth part of the whole, and in the most usual degrees of heat within a hundredth; and to this number of figures the areometer, or hydrometer, shewing the specific gravities, could be suited. A further reason for continuing only to three places of figures is, that, accurate as Mr. GILPIN's experiments have been, some irregularities are found in the two last of the five decimals to which his tables are calculated. The greatest of these irregularities, I think, do not exceed the quantity corresponding to a difference of one-fifth of a degree of heat, and in general they are much less. A table might be constructed to shew what the numbers would probably have been, to the five places of decimals, if there had been no kind of error in the experiments.—Another table should be of the volumes, exhibiting what proportion the spirit and water bore to each other by measure or bulk, in the different mixtures; whence might be calculated a very useful table of Diminutions, to shew when a given weight, or volume, of a certain spirit and wa-

ter are mixed together, how much their bulk would be diminished; or, what is called by the distillers the *concentration*. From such a table the distiller could learn, what quantity of water he must mix with spirit of a given strength, in order to reduce it to proof spirit, or any other strength; and likewise what quantity of proof spirit, or spirit of any other strength, he may obtain, by adding water to spirit of a given strength; both circumstances very necessary to be known in the trade, and which some of the sliding rulers now in use profess to point out.

It may appear odd, that no mention has been made till now of *proof spirit*, the standard to which most of the regulations of the excise have hitherto been referred. The reasons for not adopting this standard are: first, that the strength of spirit to be called proof is a mere arbitrary point, and by no means so exactly determined as could be wished; and, secondly, that it seemed most convenient to take for the standard the highest strength of spirit usually found in commerce, and beyond which it cannot be rectified without a process of some expense, so that all the other degrees of strength might be reckoned one way, without the intervention of a middle point, inducing the necessity of denominating some *above* and others *under*. If, however, Government should find it expedient to preserve the reference to proof spirit, from the tables given in this Report others may be constructed, in which all the old terms of over and under proof should be retained, and have a precise meaning, as soon as the strength to be called proof shall be finally settled. By the A&t of 2 Geo. III. it is ordered, that the gallon of brandy or spirits of the strength of one to six under proof, shall be taken and reckoned at 7 lb. 13 oz., which is understood by the trade to mean at  $55^{\circ}$  of heat. Hence,

taking the weight of a gallon of water at the same heat to be 8 lb. 5,66 &c. oz. \*, the specific gravity of this diluted spirit will be found ,9335 at 60° †; whence, by a computation founded on the tables in this Report, the specific gravity of proof spirit will come out ,916. But the rulers of correction belonging to DICKS's and QUIN's hydrometers give the specific gravity of proof spirits about ,922 at 55°, equivalent to ,920 at 60°. The former, ,916, corresponds to a mixture of 100 parts of spirit with 62 by measure, or 75 by weight, of water; and the latter, ,920, to a mixture of 100 parts of spirit and 66 by measure, or 80 by weight, of water. The difference is considerable; but the first is undoubtedly most conformable to the existing Acts of Parliament. If, therefore, it be thought right to preserve the term proof-spirit in our Excise Laws, it may be understood to mean spirit, whose specific gravity is ,916, and which is composed of 100 parts of rectified spirit at ,825, and 62 parts of water by measure, or 75 by weight; the whole at 60 degrees of heat.

I have chosen this point of the thermometer, 60°, in preference to 55°, because it is much the most suitable for experiments, being the temperature at which a room feels pleasant, and in which any operation, however slow and tedious, can be executed without the uneasy sensation of cold: for this reason it has been adopted by many English philosophers. In the table formerly recommended, from 40 to 80 degrees of the thermometer, it will be the middle temperature.

\* Probably 8 lb. 5,72 oz. is nearer.

† This specific gravity indicates a mixture of 107 grains of water with 100 of spirit, and consequently is below Mr. GILPIN's present Tables, which go only to equal parts.

The specific gravity of ,825 having been fixed upon as the standard of rectified spirit in our tables, Mr. GILPIN was desired to ascertain by experiment what proportion of water would be necessary, to reduce the lightest alcohol in his possession to that standard. This was some alcohol, already mentioned, which Mr. LEWIS had furnished; and its specific gravity being ,814196 at 60°, 3000 grains of it mixed with 135 grains of distilled water formed a compound, whose specific gravity was ,825153; that is, in round numbers, 100 grains of alcohol at ,814 with 4,5 grains of water, form our standard of spirit at ,825.

Perhaps some persons may object to the preceding experiments, on account of the small quantities mixed and weighed. Undoubtedly experiments on a large scale have some advantages; but these in general depend more on the coarseness of tools, and clumsiness of operators, than on the nature of the operations. If instruments be exceedingly exact, and the experimenter equal to the task of using them properly, I believe the errors upon moderate quantities will be quite as small in proportion as upon large; and in this particular instance, where the greatest source of error lay in the determination of the heat, the smaller quantities had in that respect an evident advantage, it being much easier to bring six ounces of a liquor to an uniform temperature than so many gallons. One of our most essential instruments, namely, the balance, was so much superior in nicety to any thing that could be wanted in these experiments, that error in weighing must be thrown entirely out of the question. It was constructed by Mr. RAMSDEN; and some account, though very imperfect, of its admirable mechanism, as well as of its extreme sensibility, even when

loaded with considerable weights, has been given in the XXXIII<sup>d</sup> volume of the *Journal de Physique*.

I must not conclude this part of the Report without observing, that as the experiments were made with pure spirit and water, if any extraneous substances are contained in the liquor to be tried, the specific gravity in the tables will not give exactly the proportions of water and spirit in it. The substances likely to be found in spirituous liquors, where no fraud is suspected, are, essential oils, sometimes empyreumatic, mucilaginous or extractive matter, and perhaps some saccharine matter. The effect of these, in the course of trade, seems to be hardly such as would be worth the cognizance of the excise, nor could it easily be reduced to any certain rules. Essential and empyreumatic oils are nearly of the same specific gravity as spirit, in general rather lighter, and therefore, notwithstanding the mutual penetration, will probably make little change in the specific gravity of any spirituous liquor in which they are dissolved. The other substances are all heavier than spirit; the specific gravity of common gum being 1,482, and of sugar 1,606, according to the tables of M. BRISSON. The effect of them therefore will be to make spirituous liquors appear less strong than they really are. An idea was once entertained of endeavouring to determine this matter with some precision; and accordingly Dr. DOLLEFUS evaporated 1000 grains of brandy, and the same quantity of rum, to dryness; the former left a residuum of 40 grains, the latter only of  $8\frac{1}{2}$  grains. The 40 grains of residuum from the brandy, dissolved again in a mixture of 100 of spirit with 50 of water, increased its specific gravity ,00041; hence the effect of this extraneous matter upon the specific gravity of the brandy containing it would be to increase the fifth decimal by 6 nearly, equal

equal to what would indicate, in the above-mentioned mixture, about one-seventh of a grain of water more than the truth, to 100 of spirit : a quantity much too minute for the consideration of Government.

## P A R T II.

*On Hydrometers.*

THE readiest way of ascertaining specific gravities, and undoubtedly the most convenient for public business, is by hydrometers ; and, I conceive, those of the simplest construction to be best upon the whole, especially if more accurate means are kept at hand, to be resorted to in case of disputes. An hydrometer of glass would be the most certain ; but whether it be of that substance, or of metal, it should consist of a ball, or rather bulb, so poised as that a certain part should be always downmost in the liquor, and having a stem rising from it on the opposite part, which would consequently keep upright in using the instrument. On the size of this stem, the sensibility of the hydrometer chiefly depends. In the old areometers the stem was made so large, that the volume of water displaced between its least and greatest immersions was equal to the whole difference of specific gravity between water and alcohol, or perhaps more ; whence its scale of divisions must be very small, and could not give the specific gravity with much accuracy. To remedy this defect, weights were introduced, by means of which the stem could be made smaller, each weight affording a new commencement of its scale ; so that the size of the divisions on a given length of stem was doubled, tripled, quadrupled,

quadrupled, &c. according as one, two, three, or more weights were employed, the diameter of the stem being lessened in the subduplicate proportion of the increased length of the divisions. Of late this principle seems to have been carried to excess; the number of weights adapted to some hydrometers being so great as to prove very inconvenient in practice. A mean between the two methods would certainly be best, which might be suited to our tables in the following manner.

It is proposed to determine the specific gravity to three places of decimals, water being taken as unity: the whole compass of numbers, therefore, from rectified spirit to water, at 60 degrees of heat, would be the difference between ,825 and 1,000, that is, 175; call it 220 to include the lightest spirit and heaviest water, at all the common temperatures. Of these divisions the stem might give every twenty, and then ten weights would be sufficient for the whole 220. By making the stem carry twenty divisions, an inconvenience much complained of, that of shifting the weights, would in great measure be avoided; because a person conversant in such business would seldom err to that extent in judging of the strength of his spirit previous to trial; and yet the stem would not need to be so large, or the divisions so small, as to preclude the desired accuracy. In conformity to this arrangement it would be proper, that the weights adapted to the hydrometer should be marked with the numbers of the specific gravity, zero on the top of its stem, without a weight, being supposed to mean 800, and 20 at the bottom of the stem to signify 820, which number the first weight would carry; the successive weights would be marked 840, 860, &c.; and the division on the stem cut by the fluid under trial would be a number to be always added to the number marked upon the weight, the sum of the two shewing

shewing the true specific gravity. The weights should unquestionably be made to apply on the top of the stem, so as never to come into contact with the liquor; and in using the hydrometer its stem should always be pressed down lower than the point at which it will ultimately rest, that by being wetted it may occasion no resistance to the fluid. The instrument itself should be of as regular a shape, and with as few inequalities and protuberances, as possible, that all unnecessary obstruction to its motions may be avoided.

As it is not probable but disputes will sometimes arise, I think it would be advisable, that some of the principal excise offices should be provided with a good pair of scales, and a weighing-bottle properly marked, the quantity of whose contents of distilled water at  $60^{\circ}$  had been previously determined. By filling this bottle up to the mark with the spirit in question, and dividing its increase of weight by the given weight of water required to fill it, the specific gravity of the spirit would, I think, be better ascertained, even under the management of a common operator, than by the most dexterous use of the hydrometer.

The simplest and most equitable method of levying the duty on spirituous liquors would be, to consider rectified spirit as the true and only excisable matter. On this principle, all such liquors would pay exactly according to the quantity of rectified spirit they contain; so that when a cask, for instance, of any spirits was presented to the revenue officer, his business would be to determine from the quantity, specific gravity, and temperature, of the liquor, how many gallons, or pounds, of rectified spirit enter into its composition; each of which gallons, or pounds, should be charged a certain sum. The complicated regulations attending the adaption of the duties to different

different degrees of strength would thus be avoided; and it is believed, that many frauds might be prevented, which artful persons have now an opportunity of practising, by altering the strength of their spirit in a variety of ways. From the tables already recommended, it would be easy to deduce this quantity of rectified spirit, either by weight or measure, in any given quantity of a spirituous liquor; or other tables might be constructed which should shew it at once by inspection.

If, however, it be thought by Government most expedient not to make any essential change in the present manner of collecting this article of the revenue, I would at least recommend, that the specific gravity should be substituted for the relation to proof spirit. Thus, instead of ordering so much duty *per* gallon to be paid by spirits one to six under proof, it may be enacted, that the same sum shall be paid by spirit of ,9335 specific gravity, or, not to be too precise, by spirit from ,930 to ,935, and so on for any other degrees of strength; a certain temperature, suppose 60°, being always understood to be meant when specific gravity is mentioned in an Act of Parliament.

The duties to be laid according to either of these methods may readily be adjusted or equalized to those paid at present, as far as the latter can be determined from the Act of 2 George III. referred to above, or by any of the instruments now in use.

It will give me very sincere pleasure if the preceding experiment and remarks should tend to advance the prosperity of this country, by introducing a more just and advantageous mode of collection into so material a branch of the revenue.

